• E-mail: practicalwireless@warnersgroup.co.uk

Ionospheric Pioneers

Steve White G3ZVW reviews the discovery of the ionosphere and some of those who played a part in it.

A lot of people think that Marconi discovered radio. He didn't, although he certainly knew how to exploit it commercially. What he actually did was build on the work of other scientists and mathematicians who came before him. In this instalment of *Making Waves* I want to go back in time and look at the discovery of what we now call the ionosphere. While some *PW* readers will no doubt be able to cite the names of others who made a contribution, this is my take on the subject.

The 19th Century

The first person to think that there might be a radio ionosphere was German mathematician and physicist **Carl Friedrich Gauss**. The year was 1839. He postulated that an electrically conducting region of the atmosphere could account for the observed variations of Earth's magnetic field. Although he didn't name what we now call the ionosphere, to this day the unit of magnetic flux density (the strength of a magnetic field) is named after Gauss.

Sir Edward Sabine was an Irish astronomer who led the effort to establish a system of magnetic observatories in various parts of British Empire. He showed the link between sunspots and magnetic storms.

Balfour Stewart was a Scottish scientist who became Director of the Observatory at Kew and by an enormous stroke of good luck he did so at exactly the right time, 1859. He recorded the Super Flares on the Sun on August 28th and September 2nd 1859. Major Auroras were trigged by both, but neither event is named after him.

What became known as the Carrington Super Flare of September 2nd 1859 was the second of the above two. **Richard Carrington** himself was English and an amateur astronomer. Although there was strong evidence, Carrington was extremely cautious so unwilling to state that there was a definite association between the Solar Flares and the magnetic storms that took place on Earth at that time. He was the man who proved that not all of the Sun rotates at the same speed (it is faster near the equator and slower near the poles), with the Carrington Rotation Period of the Sun being named after him.

It is now known that when Solar Flares take place – Coronal Mass Ejections (CMEs) as they are also known – not all the energy and particles released travel at the same speed. The first wave contains a lot of X-rays, travels at light speed and reaches Earth in eight minutes. The second wave contains plasma (electrically charged particles) and can arrive hours to a few days later. The events of 1859 were observed and, perhaps more importantly, recorded automatically by a magnetograph at the Observatory in Kew, although it would be another 80 years before the link between the Solar Flares and the effect that one can have on the ionosphere would be proved.

1

Carl Friedrich Gauss (1777 to 1855), portrait by Christian Albrecht Jensen (source: Wikipedia).

In 1864 Scottish scientist and mathematical physicist **James Clerk Maxwell** formulated the classical theory of electromagnetic radiation, bringing together for the first time electricity, magnetism and light as different manifestations of the same phenomenon. Radio waves are electromagnetic and Maxwell also has things associated with electromagnetism named after him, including Maxwell's Corkscrew Rule and Maxwell's Right Hand Rule.

Radio Silence

At this point it is worth reminding readers that in 1859 radio had not been discovered, so there are no reports of how the Solar Flare that caused the Carrington Event affected radio propagation. Even though no subsequent Solar Flares have been as large, we can say that there would have been an immediate absorption event. High frequency radio would have suffered an immediate fadeout, so if there had been any listeners, they would have been left listening to eerily quiet receivers. The only things they would have been able to hear would have been local stations and local interference – transmissions within Ground Wave range. The radio silence during a magnetic storm is explained by the behaviour of the D Region of the ionosphere, which is the Region that absorbs radio signals. It is the lowest part of the ionosphere and under normal conditions only absorbs frequencies up to a couple of Megahertz (and even then only during daylight hours). However, when a solar storm occurs it becomes more highly ionised and the frequencies that it absorbs stretch ever higher.

On VHF, the auroras that were seen during the Carrington Event would have resulted in VHF enthusiasts heading into their shacks to make long distance contacts, had there been any! Most of the time auroras are confined to the Polar Regions of Earth and many are not particularly bright. Rarely do they extend to mid-latitude countries such as Germany and France, but auroras from the Carrington Event were visible into the tropics. In the Northern Hemisphere the auroras were observed as far south as Mexico and were said to be so bright that at night it was possible to read a newspaper by their light.

IEEE MILESTONE IN ELECTRICAL ENGINEERING AND COMPUTING
Maxwell's Equations, 1860–1871
Between 1860 and 1871, at his family home Glenlair and at King's College London, where he was Professor of Natural Philosophy, James Clerk Maxwell conceived and developed his unified theory of electricity, magnetism and light. A cornerstone of classical physics, the Theory of Electromagnetism is summarized in four key equations that now bear his name. Maxwell's equations today underpin all modern information and communication technologies.
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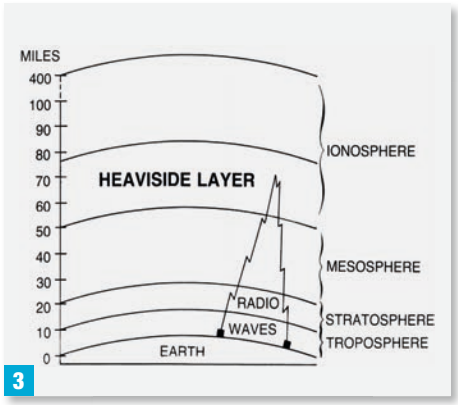
2



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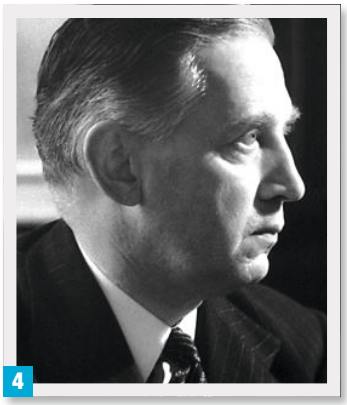
4

2. One of three plaques commemorating Maxwell's equations. One is at King's College, one at Maxwell's birthplace in Edinburgh and one at the family home in Glenlair. (source: Wikipedia). 3. The Heaviside (Kennelly-Heaviside) layer. The various reflecting layers were subsequently designated D, E, F. Why not A, B, C? Because, at the time, it was not clear whether additional layers would be discovered. 4. Sir Edward Appleton (1892 to 1965). (source: Wikipedia)

If there had been any satellites in orbit back then, they would have had a 'bad day at the office'. Satellite electronics are shielded against the effects of magnetic storms but the shielding doesn't include the solar panels they use to charge their batteries. There might have been failures and the increased particle count in the Solar Wind would have caused additional drag, so some might even have shifted orbit.

The 20th Century

In 1901 a radio signal transmitted by **Guglielmo Marconi** was received across the Atlantic Ocean for the first time. The path was Poldhu in Cornwall to Newfoundland in Canada. For that message to have been propagated it must have been reflected or refracted not once but twice from something outside Earth's lower atmosphere. The ionosphere was what was responsible but even in 1901 it had still not been named.

In 1902, English scientist **Oliver Heaviside** and **Arthur E Kennelly** (1898 president of the American Institute of Electrical Engineers), independently concluded that an atmospheric layer capable of conducting electricity must exist. Their discovery became known as the Kennelly-Heaviside Layer. These days we call it the E-Layer.

In 1924 English physicist **Sir Edward Appleton** worked further on electrically conductive layers high in Earth's atmosphere. What he discovered became known as the Appleton Layer. It is a layer higher than the Kennelly-Heaviside Layer, electrically stronger and consistently able to refract short-wave radio signals around the Earth. Today we call it the F-Layer. For his work on radio propagation he was awarded the Nobel Prize for Physics in 1947.

Scottish physicist **Sir Robert Watson-Watt** seems to have been the first person to use the word 'ionosphere'. In 1926 he introduced the term in a letter, although the letter was not published until 1969 in the magazine *Nature*. He said; *"We have in quite recent years seen the universal adoption of the term 'stratosphere' ... and ... the companion term 'troposphere'... The term 'ionosphere', for the region in which the main characteristic is large scale ionisation with considerable mean free paths, appears appropriate as an addition to this series."* Watson-Watt knew about Appleton's work and study of the ionosphere and had an interest in radio direction finding – initially in finding the location of lightning strikes. He went on to invent the first practical radar, which made a huge contribution to the Allied effort in WWII.

30 years ago there was a reminder of what a magnetic storm can do, albeit nowhere near as strong as the Carrington Event of 1859. On March 10th 1989, during the peak of Solar Cycle 23, there was a large CME from the Sun. On Earth communications were immediately interrupted but, as per normal, things then started to recover. When the plasma ejected by the Sun reached Earth three days later the resulting Magnetic Storm plunged a good part of Canada – including all of Quebec – into darkness. Long overhead power lines had huge currents induced into them, which caused transformers to overheat and some to catch fire. During this magnetic storm auroras were visible across most of the USA and as far south as Cuba.

Modern Practice

So, what would happen if another magnetic storm of the same magnitude as the 1859 Carrington Event happened again?

The problem of high currents induced into long electrical power lines during magnetic storms is now well understood, so countries that mitigate against the problem by being able to break their electrical grid up into segments should fare okay as regards power outages. Being a relatively small country, Great Britain doesn't have power lines as long as vast countries such as Canada and Russia. Even so, in 2010 the UK Government's Science and Technology Committee held a session to take evidence of the Government's ability to deal with space weather events. You can read about it (see the link below, for example) and watch the video online. **https://tinyurl.com/y3a9se72**

Satellites could be damaged or displaced from their intended orbit but the internet and telephone traffic are increasingly carried by fibre-optic cables rather than satellites. Optical fibres are not electrically conductive, so telecomms might not be greatly affected. Having said that, the world relies increasingly on accurate timing and many of those signals are derived from the GPS network. GPS satellites could be affected, so inaccurate timings from them could result in navigational errors.

If your domestic phone/internet is delivered via a copper line, there's no need to worry because that line is only going to be a few miles long at most. If it was hundreds of miles long, it might be a different story and if it was thousands of miles long, it definitely would be, although phone lines of that length wouldn't work anyway. If you had a long-distance phone call in progress when a magnetic storm hit Earth, you needn't be worried, because the connection is not direct end-to-end.